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BASIC REQUIREMENTS FOR ELEMENTS OF AN ELECTRIC DRIVE CONTROLLED BY MERCURY-ARC CONVERTERS

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The problem of using a mercury-arc converter (rectifier) for electric-drive purposes is attracting more and more attention. Some years ago, the work of many researchers was mainly centered on a theoretical study of the properties of such drives, while the activity aimed at practical applications was insignificant. In recent years, several heavy-duty drives, using controlled mercury-arc rectifiers, have been designed. These, for the most part, operate on a system designated as URP-D /URP is taken from the initials for "controlled mercury converter," while the full designation URP-D denotes the whole assembly, including the mercury-arc rectifier feeding into an electric-drive motor/.

The question of the advisability of using a URP drive can be answered correctly only after a thorough analysis of the problem from a technical and economic standpoint. Hasty selection of the type of converter or an unsuitable converter characteristic can negate all the advantages of the system, make it uneconomical, cumbersome, etc. Sometimes the numerous assets of the URP-D system can be offset by a cumbersome cooling system entailing water supply, construction of a cistern, etc., thereby making the system uneconomical.

The URP-D system comprises a controlled mercury rectifier in conjunction with one of the following: (1) an independently excited dc motor; (2) an induction cascade consisting of an induction motor and two converters, or (3) a "valve motor" /electric motors fed by ionic rectifiers; e.g., thyratron motor/. In each case, the requirements for the drive elements are of a specific nature. For example, the URP-D system requires smooth variation of the control (firing) angle; for an induction motor cascade, one must be able to form a bridge system from the rectifier tubes, and so on.

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Two main groups of drives can be distinguished depending on load conditions: (1) drives with current peaks at full (rated) voltage and (2) drives with peaks at low voltage.

As is well known, converter operating conditions depend considerably on the relationship between current and voltage peaks. When examining the requirements for the basic elements of a drive, regardless of circuit and load conditions, it is advisable to consider separately the three basic elements of the system: (1) the valves /mercury-arc rectifiers/; (2) the main circuit; (3) the control circuit.

Mercury-Arc Rectifiers

The rectifier units should function reliably under all conditions. From this viewpoint, preference should undoubtedly be given to the multianode unit over the single-anode unit.

Regarding the need for special designs, it should be noted that all existing URP designs satisfy the needs of the URP-D system. Substantial changes should be introduced in the designs of certain rectifiers intended for induction cascades and for thyratron-type motors, because of the necessity for bridge connection of the rectifier units. For this type of drive, only single-anode units with separate pumping and cooling systems can be used. In such cases, it is best to use sealed rectifiers with air cooling.

The most serious requirement made by the drive on the rectifier is the necessity for grid control over the full range of operation, i.e., regulation must be possible from zero to maximum voltage. A rectifier which does not satisfy this requirement, or only partially satisfies it (10-15% grid control), cannot ensure normal operation of the drive and, as a rule, cannot be recommended for such purposes. It is most important that the overload capacity of the rectifier should be at least equal to the overload capacity of the motor and transformer over the full range.

For example, for a rolling-mill drive with an 1,800-kw, 600-v, 3,000-amp motor, whose starting peak current is one and a half times the rated value, and takes place at 10% voltage, it is necessary to use two converters, type RMNV 500 x 6 rectifiers, as their permissible overload capacity, equal to 1.5 rated load at full voltage, must be almost halved for large control angles ($I_{permissible} = 1.5 \times 3{,}000 \times 0.5 = 2{,}250$ a). At full load, the two rectifiers will be used at only half their capacity. (See B. V. Peretts and Z. P. Zolotukhina, "Selecting the Proper Control Range for a Regulated Mercury Converter-Motor System Operating With Power Regeneration in the Circuit," Promyshlennaya Energetika, No 2, 1949)

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This circumstance should be borne in mind both when planning electric drives and when improving rectifiers, whose load capacity should be increased. It is desirable to produce a special design capable of withstanding brief 50-100% overload over the whole control range. Also, the pumping and cooling circuits of rectifiers used for drive purposes must be as reliable and simple as possible.

The most acceptable type of rectifier for drive purposes is the air-cooled, single-anode, sealed-tube unit whose design enables bridge circuits to be used and ensures that reserve tubes can be brought into operation quickly. The reserve problem is often the most important.

Main Circuit

In examining the requirements for the main circuit, the first thing to point out is the necessity for a reliable transformer which is capable of withstanding possible arc-backs.

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The choice of the feed circuit is also determined by the relative magnitude of the higher harmonics which appear in the voltage curve during regulation. In this respect, a circuit with a dividing coil is to be preferred to a circuit with a double zigzag.

The transformer inductance should, on the one hand, be selected in conjunction with other inductances of the main circuit, as their sum is related to the inductance of the cathode reactor. Since the inductance of the transformer also determines the flexibility of the mechanical-drive characteristic, e.g., in the URP-D system, its parameters must always be selected in conjunction with those of the whole electric-drive system.

A cathode reactor in the main circuit helps to smooth out the rectified current, which is desirable as a rule, but, on the other hand, increases the probability of arc-backs and makes the system more liable to operate periodically /hunting/ in transitional processes. Thus it is difficult to formulate general requirements for a reactor; its parameters must be established for each particular concrete case.

When designing URP-D reversing systems with one rectifier, it is necessary to provide for current reversal in the main circuit. Since the reversing circuit should be used extensively in small and medium power drives, it would be advisable to master the production of high-speed, automatic equipment which would also serve as protective devices by breaking the main circuit during short circuits or arc-backs.

In designing electric-drive systems with controlled mercury rectifiers, it should not be forgotten that the drive motor operates under unusual conditions and will have to satisfy special requirements. For example, in the URP-D system, the effect of high harmonic currents cannot be neglected. Apart from the unpleasant "hum," high harmonics cause additional heating of the steel circuits of the machine, which, in large electric motors, must be given special consideration. In designing a motor it is also desirable to concentrate all the necessary inductance of the main circuit in the armature, to avoid additional devices in the form of cathode reactors.

Control and Protection Circuits

A clear arc, which is a necessary condition for a rectifier irrespective of its field of application, is of special importance under drive conditions. The basic requirements for a rectifier control circuit operating in a drive system differ considerably from those for a rectifier substation. Whereas, in the latter case, all that is required is the establishment and maintenance of some control angle, in the former case, the control angle must change almost continuously (in reverse drives), in accordance with a definite law which will give the mechanical characteristic needed.

The grid-control system must fit in with the general scheme of automatic-drive control. To make the URP drive as inertialess as modern systems with electromechanical amplifiers /e.g., amplidynes/, special attention should be paid to the automatic control circuit. The widespread opinion that the URP drive is inertialess is correct only when the control system is inertialess. For example, the speed of the transitional processes when a phase shifter is used in the grid circuit is determined by the inertia of the phase shifter motor.

The control cabinets produced by the plants should contain apparatus having a minimum time constant. Apparatus suitable for grid control at substations may not satisfy the needs of a drive. It should be noted, however, that it is possible and may prove advisable to use an electromagnetic transitional process in the control apparatus to create the required transitional electromechanical process.

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When producing reactors, peak transformers, etc., supplementary windings or a space for them, should be provided to ensure compounding of the rectifier or achieving the desired mechanical characteristic. It should also be possible to obtain the necessary control-pulse width to ensure operation under regenerative, as well as motor, conditions.

In examining the requirements for the basic elements of an electric drive with URP, one should estimate to what degree they can be met satisfactorily in the light of present-day rectifier construction. USSR industry is in a position to produce instruments and apparatus to satisfy almost every requirement.

The design of electric drives with controlled rectifiers over a wide power range, from a machine tool to the main drive for a billet rolling mill, requires various types of rectifiers. The following subdivisions may be considered expedient, in accordance with present USSR practice:

1. For small drives, RS rectifiers -- mercury, glass containers, multianode (kilowatts, tens of kilowatts).

2. For medium drives, RM rectifiers -- mercury, sealed metal tank, with air cooling; and RMV -- mercury, sealed metal tank, with water cooling (tens, hundreds of kilowatts).

3. For large drives, RMNV rectifiers -- mercury, metal tank, with vacuum pump and water cooling (hundreds and thousands of kilowatts).

It should be remembered that incorrect rectifier selection does away with all the advantages of the system, and discredits it.

Industry in the near future needs complete deliveries of regulated electric drives with a wide range of controlled mercury-arc rectifiers. Electric-machine-building plants must immediately prepare for the production of complete assemblies, including the transformer, URP, motor, and control system. All the possibilities exist for wide-scale use of these new, economical electric-drive systems. Their advantages are incontestable. Therefore, they should be of special interest not only to the manufacturers, but also to industries using the equipment (metallurgy, mining, machine-tool building, etc).

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